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Risk factors for bacterial gill disease in young rainbow trout (*Oncorhynchus mykiss*) in North America

Julie Bebak [a,*], Mona Baumgarten [b], Gary Smith [c]

[a] *Freshwater Institute, P.O. Box 1746, Shepherdstown, WV 25443, USA*

[b] *University of Pennsylvania, Department of Biostatistics and Epidemiology, 829 Blockley Hall, Philadelphia, PA 19104-6021, USA*

[c] *University of Pennsylvania, School of Veterinary Medicine, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348, USA*

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Abstract

A retrospective whole-population survey was used to investigate putative risk factors for bacterial gill disease (BGD) in young hatchery-reared rainbow trout in North America. Three sets of analyses were done. The first analysis included as cases all of the hatcheries in which there was at least one outbreak of BGD during the 2-year study interval, regardless of location of the outbreak in the hatchery. The case group for the second analysis was limited to hatcheries for which the BGD outbreak occurred inside the hatch house. The case group for the third analysis was limited to hatcheries for which the BGD outbreak occurred outside of the hatch house. For the logistic regression that combined all cases of BGD (regardless of location of the outbreak), there was a significant association between mortality from bacterial gill disease and previous experience with BGD outbreaks (odds ratio (OR) = 10.1; 95% confidence interval (CI) = 5.6, 18.2), being a commercial trout hatchery (OR = 5.2; 95% CI = 2.6, 10.4), and being a hatchery with an annual salmonid fish production of > 250 000 fish (OR = 2.9; 95% CI = 1.5, 5.7). For BGD outbreaks that occurred in the hatch house, the presence of fish in the hatch house water supply significantly increased the odds of an outbreak (OR = 5.3; 95% CI = 2.2, 12.6), as did the use of ultraviolet radiation to disinfect the hatch house water (OR = 7.5; 95% CI = 2.2, 25.8), previous experience with bacterial gill disease (OR = 19.3; 95% CI = 7.9, 46.8), and being a commercial hatchery (OR = 7.7; 95% CI = 3.2, 18.6). The odds of a BGD outbreak outside of the hatch house was

* Corresponding author.

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significantly associated with previous experience with BGD (OR = 4.3; 95% CI = 2.2, 8.6) and with being a hatchery with an annual salmonid fish production > 50,000 pounds (OR = 2.5; 95% CI = 1.2, 5.1).

Keywords: Bacterial gill disease; Epidemiology; Rainbow trout; Risk factors; Salmonid

1. Introduction

Bacterial gill disease (BGD) is a major cause of epidemic morbidity and mortality in cultured salmonid fish (Daoust and Ferguson, 1983; Bullock, 1990). Historically, species of *Flavobacterium, Cytophaga* and *Flexibacter* have been implicated as etiologic agents of BGD (Bullock, 1972), but recently the consensus seems to be that *Flavobacterium branchiophilum*, a yellow-pigmented, filamentous, Gram-negative bacterium, is the etiologic agent for BGD (Kimura et al., 1978; Wakabayashi et al., 1980; Farkas, 1985; Wakabayashi et al., 1989; Heo et al., 1990; Von Graevenitz, 1990; Ferguson et al., 1991; Ostland et al., 1994). *F. branchiophilum* is horizontally transmitted, and clinical disease has been experimentally induced in fingerling and adult salmonids (Ferguson et al., 1991). Putative risk factors for BGD outbreaks in cultured trout have been suggested by Bullock (1972) and MacPhee et al. (1995). No studies have been published that identify risk factors for mortality from BGD. This paper presents the results of a study that identified risk factors for BGD in rainbow trout (*Oncorhynchus mykiss*) less than 6 months old that were raised from eggs in trout hatcheries in the USA and Canada.

2. Methods

2.1. Trout hatcheries surveyed

A questionnaire was mailed to 1168 private, state and federal hatcheries in the USA and 382 private, provincial and federal hatcheries in Canada that were registered for trout production in 1993–1994. Hatchery owners/managers were asked to complete the questionnaire if they raised rainbow trout (including the kamloops and steelhead strains) from eggs at any time between July 1992 and July 1994. If rainbow trout were not raised from eggs, the respondent was asked to return the questionnaire so that hatchery ineligibility could be recorded and per cent response could be estimated.

The questionnaire was mailed to the USA hatcheries in July 1994. A list of government hatcheries was obtained from Turner et al. (1993), and lists of commercial hatcheries were obtained from the state agencies responsible for hatchery registration and from national and state trout industry organizations. Non-responding US hatcheries were sent two reminder letters. The mail questionnaire was converted to a telephone survey, and from December 1994 to March 1995 the remaining non-responding US hatcheries were contacted by telephone and invited to complete the questionnaire. In order to ensure that the probability of recall bias in the telephone survey was the same as

in the mail survey, respondents were asked about hatchery conditions during a more recent period, between January 1993 and December 1994.

The questionnaire was mailed to Canadian hatcheries, except those in New Brunswick and Quebec, in December 1994, and to New Brunswick and Quebec hatcheries in April 1995. For New Brunswick and Quebec provinces, questionnaires were presented in English and in Canadian French. Government and commercial hatchery lists for each province were obtained from provincial fisheries personnel. Non-responding Canadian hatcheries were sent a reminder letter and were telephoned about 6 months after the original mailing to determine whether they would have been eligible for the study.

3. Questionnaire

Questionnaire design followed the recommendations of Dillman (1978). Questions inquired about conditions in the hatchery, including use of a hatch house (building where trout eggs are incubated and hatched, and fry are reared), presence of fish in hatch house and pond/raceway water supply, use of disinfectants for hatch house water supply, previous history of BGD outbreaks, outbreaks of other diseases affecting young rainbow trout, fish culture density, and yearly production in numbers and pounds of salmonid fish. If a hatchery had a BGD outbreak during the study interval, the respondent was asked to provide information about the first outbreak, including location (hatch house or pond/raceway) and whether a laboratory or fish health specialist was involved in the diagnosis. Respondents were also asked whether any of the hatchery conditions referred to in the survey had changed during the study period.

3.1. Definition of a disease outbreak

The high numbers and small size of young cultured fish makes it likely that disease will be unnoticed until clinical signs or mortality exceed the level normally observed in daily facility operations. Therefore, a disease outbreak was defined as mortality that occurred above the expected day-to-day baseline level.

3.2. Data analysis

The survey was designed to use case-control methodology for the analysis. Three sets of analyses were undertaken, using three sets of cases and controls (StataCorp, 1995). Control:case ratios greater than 1.0 were used to increase study power (Schlesselman, 1982).

In the primary analysis, the cases were the hatcheries where at least one outbreak of BGD occurred during the 2-year interval in rainbow trout that were < 6 months old and were hatched from eggs at the facility. The controls were the hatcheries reporting no BGD outbreaks, those reporting BGD outbreaks before July 1992, and those reporting outbreaks in fish ≥ 6 months old.

The second and third analyses were exploratory, and were subsets of the entire sample of hatcheries. In the second analysis, the case group was restricted to hatcheries

where the described BGD outbreak occurred in the hatch house. The controls were the same controls as for the first analysis, excluding those hatcheries that did not use a hatch house. Hatcheries not using a hatch house were excluded because they did not have the same probability of becoming a case as hatcheries that did use a hatch house, which is one requirement for selection of controls for a case-control study (Rothman, 1986). The cases for the third analysis were those hatcheries where a BGD outbreak occurred outside the hatch house. The controls were as described in the first analysis.

For each analysis, the effect of exposure to each risk factor was first evaluated using a univariable analysis. The 95% confidence intervals for the odds ratios were estimated using the Cornfield approximation, and the significance of associations was tested using the Pearson chi-square statistic ($\alpha = 0.05$).

Variables for which the P-value was ≤ 0.25 in the univariable analysis were included in a multivariable logistic regression. A backward selection procedure was then used in which the variable with the largest P-value (likelihood ratio chi-square, $\alpha = 0.05$) was removed from the model and the new model was compared to the previous one (Hosmer and Lemeshow, 1989).

All statistical tests were two-tailed. Interaction effects were not tested because low sample sizes and low-frequency categories would have severely limited the power of an analysis to detect an interaction (Selvin, 1996).

All variables included in the analyses were dichotomous. For the variables related to hatchery production, the cutpoint used to define the dichotomous variable was the median of the distribution of production values.

4. Results

4.1. Survey response

For the USA, about 38% (448/1168) of the hatcheries queried were eligible for the study, and 367 of the 448 eligible hatcheries completed the questionnaire, a response rate of 82%. The remaining US hatcheries were ineligible by study criteria (569/1168), considered out of business (118/1168), or could not be contacted (33/1168).

For Canada, excluding Quebec, 40% (98/245) of the hatcheries queried were eligible for the study. Of the 98 eligible hatcheries, 53 completed the questionnaire—a response rate of 54%. The remaining hatcheries were ineligible by study criteria (103/245), considered out of business (41/245), or could not be contacted (3/245). Of the 137 questionnaires sent to hatcheries in Quebec province, four were completed. Of the remaining 133 hatcheries, five were eligible, 50 were ineligible, 12 were considered out of business, and 66 hatcheries could not be contacted despite repeated efforts.

4.2. Selection and categorization of hatcheries for data analysis

A total of 424 hatchery questionnaires were putative candidates for data analysis (367 from the USA and 57 from Canada). Twenty out of the 424 questionnaires were excluded either because changes were made at the hatchery during the study period that

could have affected exposure to a risk factor, because respondents did not complete at least 75% of the questions, or because respondents did not know whether a BGD outbreak occurred in their hatchery or did not answer the question about BGD outbreaks. Thus, 404 hatcheries were eligible to be assigned as cases or controls. These eligible hatcheries were categorized as government or as commercial facilities. This assigmnent resulted in 45% (183/404) government facilities and 55% (221/404) commercial hatcheries being eligible to be cases or controls.

4.3. Incidence, location and diagnosis of BGD outbreaks

Of the eligible hatcheries, 32% (131/404) of the respondents reported at least one BGD outbreak and of those hatcheries reporting the location of the outbreak (116/131), 52% (60/116) occurred in the hatch house and 48% (56/116) occurred outside the hatch house. A diagnostic laboratory or fish health specialist was used by 48% (57/119) to assist in the diagnosis of BGD. Government hatcheries (76%; 35/46) were significantly more likely than commercial hatcheries (30%; 22/73) to use a laboratory or fish health specialist for the diagnosis of BGD (Pearson chi-square with 1 degree of freedom = 23.9, $P < 0.001$).

4.4. Analysis of all cases of BGD

The cases for this analysis were the 131 hatcheries that experienced at least one outbreak of BGD. The controls were the 273 farms that did not experience a BGD outbreak. The control group included the 15 respondents that reported BGD outbreaks in fish ≥ 6 months old or before July 1992 (Table 1).

One hundred and seventy-five respondents could not provide information about fish density. Including fish density in the logistic regression model would have severely decreased the power of the analysis because many observations would have to be excluded due to missing values. In exploratory logistic analyses using only the hatcheries for which fish density was known, the fish density variables were not significant. Therefore, the fish density variables were excluded from all logistic regressions.

The presence of collinearity in a logistic regression model is indicated by the instability of estimated odds ratios and their standard errors as variables are added or substracted during the modelling process (Pagano and Gauvreau, 1993). For this analysis, and the two subsequent analyses, there were no indications of collinearity as the risk factors were screened through to the final logistic regression models.

In the logistic regression model for all cases of BGD combined (Table 2), the odds of a BGD outbreak was significantly increased with the presence of wild or escaped fish in the hatch house water supply, previous outbreaks of bacterial gill disease, being a commercial hatchery, and being a hatchery that raised more than 250 000 fish per year (Pearson chi-square with 11 degrees of freedom = 7.38; $P < 0.77$).

4.5. Analysis of the cases of bacterial gill disease that occurred in the hatch house

The results of the univariable analysis for the cases of BGD that occurred in the hatch house are presented in Table 3. The presence of wild or escaped fish in the hatch house

Table 1
Univariable analysis for all cases of bacterial gill disease (131 cases, 273 controls; North America, 1992–1995)

Risk factor	Number (code = 1) in cases /total number of cases	Number (code = 0) in controls /total number of controls
Water supply flows through cultured fish before enters hatch house (Yes = 1, No = 0)	3/129	7/263
Any wild or escaped fish live in the hatch house water supply (Yes = 1, No = 0) [a]	44/125	65/258
Hatch house water flows out to salmonid fish (Yes = 1, No = 0) [a]	79/128	145/262
Wild or escaped fish live in the pond/raceway water supply (Yes = 1, No = 0) [a]	71/122	127/258
Water disinfected with ultraviolet light before entering hatch house raceways (Yes = 1, No = 0) [a]	13/129	13/263
Bacterial gill disease outbreaks before July 1992 (Yes = 1, No = 0) [a]	97/129	75/272
Furunculosis, coldwater disease, infectious pancreatic necrosis, infectious hematopoetic necrosis or whirling disease outbreaks before July 1992 (Yes = 1, No = 0)	40/129	90/272
Per cent of fish lost to predation by birds in 1992 and 1993 (> 10 = 1, ≤ 10 = 0)	26/123	54/247
Average fish density at 1 inch (lb/cubic ft.) (> 0.5 = 1, ≤ 0.5 = 0)	45/75	85/173
Average fish density at 2 inches (lb/cubic ft.) (> 1.0 = 1, ≤ 1.0 = 0)	44/71	66/165
Commercial or government hatchery (C = 1, G = 0) [a]	79/131	142/273
Total salmonid fish production in pounds of fish for 1992 and 1993 (≤ 50000 = 0, > 50000 = 1) [a]	76/126	118/260
Total salmonid fish production in numbers of fish for 1992 and 1993 (≤ 250000 = 0, > 250000 = 1) [a]	82/127	127/264

[a] Variable screened through to the multivariate model; $P \leq 0.25$.

water supply, water disinfected with ultraviolet (UV) light before entering the hatch house raceways, bacterial gill disease outbreaks before July 1992 and being a commercial hatchery were all significantly associated in the final model with BGD outbreaks in

Table 2
Final model from logistic multiple regression for all cases of bacterial gill disease combined (number of observations, 341; North America, 1992 to 1995)

Risk factor	OR	SE	95% CI	*P*-value
Wild or escaped fish live in the hatch house water supply (Yes = 1, No = 0)	2.7	0.8	1.4–4.9	0.001
Bacterial gill disease outbreaks before July 1992 (Yes = 1, No = 0)	10.1	3.0	5.6–18.2	0.000
Commercial or government hatchery (C = 1, G = 0)	5.2	1.8	2.6–10.4	0.000
Total salmonid fish production in numbers of fish for 1992 and 1993 (≤ 250000 = 0, > 250000 = 1)	2.9	1.0	1.5–5.7	0.002

Table 3
Univariable analysis for bacterial gill disease outbreaks in the hatch house (60 cases, 263 controls; North America, 1992–1995)

Risk factor	Number in cases /total number of cases	Number in controls /total number of controls
Any wild or escaped fish live in the hatch house water supply (Yes = 1, No = 0) [a]	23/57	64/257
Hatch house water flows out to salmonid fish (Yes = 1, No = 0)	34/59	145/262
Wild or escaped fish live in the pond/raceway water supply (Yes = 1, No = 0) [a]	32/55	122/249
Water disinfected with ultraviolet light before entering hatch house raceways (Yes = 1, No = 0) [a]	10/60	13/262
Bacterial gill disease outbreaks before July 1992 (Yes = 1, No = 0) [a]	44/59	73/262
Furunculosis, coldwater disease, infectious pancreatic necrosis, infectious hematopoetic necrosis or whirling disease outbreaks before July 1992 (Yes = 1, No = 0)	18/59	88/262
Per cent of fish lost to predation by birds in 1992 and 1993 (> 10 = 1, ≤ 10 = 0)	9/59	51/238
Average fish density at 1 inch (lb/cubic ft.) (> 0.5 = 1, ≤ 0.5 = 0)	26/38	81/169
Average fish density at 2 inches (lb/cubic ft.) (> 1.0 = 1, ≤ 1.0 = 0)	26/37	65/163
Commercial or government hatchery (C = 1, G = 0) [a]	41/60	132/263
Total salmonid fish production in pounds of fish for 1992 and 1993 (≤ 50000 = 0, > 50000 = 1) [a]	31/57	114/251
Total salmonid fish production in numbers of fish for 1992 and 1993 (≤ 250000 = 0, > 250000 = 1)	33/58	126/255

[a] Variable screened through to the multivariate model; $P \leq 0.25$.

the hatch house (Table 4) (Pearson chi-square with 11 degrees of freedom = 10.88, $P < 0.45$).

4.6. Analysis of the cases that occurred outside of the hatch house

For the univariable analysis for cases of bacterial gill disease outbreaks outside of the hatch house, several of the screened through variables had screened through also into the

Table 4
Final model from logistic multiple regression for all cases of bacterial gill disease in the hatch house (number of observations, 284; North America, 1992–1995)

Risk factor	OR	SE	95% CI	*P*-value
Wild or escaped fish live in the hatch house water supply (Yes = 1, No = 0)	5.3	2.3	2.2–12.6	0.000
Water disinfected with ultraviolet light before entering hatch house raceways (Yes = 1, No = 0)	7.5	4.7	2.2–25.8	0.001
Bacterial gill disease outbreaks before July 1992 (Yes = 1, No = 0)	19.3	8.7	7.9–46.8	0.000
Commercial or government hatchery (C = 1, G = 0)	7.7	3.5	3.2–18.6	0.000

Table 5
Univariable analysis for bacterial gill disease outbreaks that occurred outside the hatch house (56 cases, 273 controls; North America, 1992–1995)

Risk factor	Number in cases /total number of cases	Number in controls /total number of controls
Any wild or escaped fish live in the hatch house water supply (Yes = 1, No = 0)	16/54	65/258
Hatch house water flows out to salmonid fish (Yes = 1, No = 0) [a]	38/54	145/262
Wild or escaped fish live in the pond/raceway water supply (Yes = 1, No = 0)	31/55	127/258
Bacterial gill disease outbreaks before July 1992 (Yes = 1, No = 0) [a]	40/56	75/272
Furunculosis, coldwater disease, infectious pancreatic necrosis, infectious hematopoetic necrosis or whirling disease outbreaks before July 1992 (Yes = 1, No = 0)	18/56	90/272
Per cent of fish lost to predation by birds in 1992 and 1993 (> 10 = 1, ≤ 10 = 0) [a]	16/52	54/247
Average fish density at 1 inch (lb/cubic ft.) (> 0.5 = 1, ≤ 0.5 = 0)	15/31	85/173
Average fish density at 2 inches (lb/cubic ft.) (> 1.0 = 1, ≤ 1.0 = 0)	15/29	66/165
Commercial or government hatchery (C = 1, G = 0)	29/56	142/273
Total salmonid fish production in pounds of fish for 1992 and 1993 (≤ 250000 = 0, > 250000 = 1) [a]	40/55	127/264

[a] Variable screened through to the multivariate model; $P \leq 0.25$.

previous two models (Table 5). In the final logistic regression model, there was a significant association between BGD outbreaks outside of the hatch house and exposure to BGD outbreaks before July, 1992 (Table 6). There was also a significant association between BGD outbreaks outside of the hatch house and being a hatchery that produced more than 50 000 pounds of fish per year for 1992 and 1993 (Pearson chi-square with 1 degree of freedom = 1.24, $P < 0.26$).

Table 6
Final model from logistic multiple regression for cases of bacterial gill disease outside of the hatch house (number of observations, 279; North America, 1992–1995)

Risk factor	OR	SE	95% CI	*P*-value
Bacterial gill disease outbreaks before July 1992 (Yes = 1, No = 0)	4.3	1.5	2.2–8.6	0.000
Total salmonid fish production in pounds of fish for 1992 and 1993 (≤ 50000 = 0, > 50000 = 1)	2.5	0.9	1.2–5.1	0.011

5. Discussion

Of the hatcheries responding to our survey, 32% reported at least one BGD outbreak, suggesting that BGD might be the most common bacterial disease affecting the trout industry in the USA and Canada. In Ontario (Canada), BGD accounts for about 21% of all diagnostic submissions from fish farms to the Fish Pathology Laboratory of the Ontario Veterinary College (Daoust and Ferguson, 1983; Speare and Ferguson, 1989).

Forty-eight per cent of the survey respondents indicated that a fish health specialist or laboratory assisted in the diagnosis of BGD. Some of the respondents who did not use a laboratory or fish health specialist for the reported outbreak might have been assisted in the diagnosis of BGD for previous outbreaks or for other outbreaks during the study interval. If so, they would have been familiar with the clinical signs of the disease and more likely to be accurate in their assumption that the outbreak was due to BGD. In addition, the clinical signs of gill disease result from respiratory distress, and are quite distinctive (e.g. increased respiratory rate, flared operculae, gasping at the water surface for air). If an error in diagnosis occurred, it is likely that a gill disease outbreak due to some other cause would have been misdiagnosed as BGD. If so, hatcheries that should have been controls would have been classffied as cases and the odds ratio would be biased towards unity.

The possibility of recall bias results from the fact that respondents were required to recall information over a 2-year interval. In addition, some of the respondents did not receive the questionnaire until up to 3 years after the beginning of the recall interval. The 2-year interval length was necessary in order to obtain enough hatcheries that had had outbreaks for sufficient statistical power for the analysis. If survey respondents from hatcheries that experienced a BGD outbreak were more likely to recall exposure to a risk factor, then differential misclassification could have occurred that overestimated the odds ratio. For example, differential recall and misclassification could have occurred if respondents that reported BGD outbreaks during the study interval were more likely to recall previous outbreaks of BGD than respondents that did not report BGD outbreaks.

Risk factors associated with BGD are poorly understood and broadly based on empirical observations of environmental conditions and management practices. There are no published studies that were specifically designed to identity risk factors for BGD. Bullock (1972) mentions poor water quality conditions such as high ammonia concentrations and low dissolved oxygen concentrations as possible risk factors, but the role of water quality in the pathogenesis of, or as a risk factor for, BGD is not clear. Ferguson et al. (1991) were able to experimentally transmit an organism with the characteristics of *F. branchiophilum* between and among adult and fingerling brook trout and rainbow trout under what was described as 'good water quality conditions' (parameters not specified). Bullock et al. (1994) reported that spontaneous outbreaks of BGD occurred in a water recirculation system even though the values for water quality parameters remained within recommended limits for trout culture. They suggested that the density at which the fingerling rainbow trout were stocked, and the suspended solids present in tank water, may have contributed to the BGD outbreaks. MacPhee et al. (1995) found significantly higher cumulative per cent mortality in rainbow trout that were fed after being exposed to *F. branchiophilum* than in fish not fed post-exposure. They suggested

that BGD is linked to the consumption of feed by the fish, and the subsequent production of CO_2 which decreases the pH at the unstirred layer at the gill, enhancing attachment of *F. branchiophilum* to the gill surface.

A history of bacterial gill disease was a risk factor for reported outbreaks. The odds ratio for this risk factor could have been biased upwards if respondents that reported a BGD outbreak were more likely to recall that a BGD outbreak had occurred previously at the hatchery, but the magnitude (3.0—4.3) and statistical significance of the odds ratios suggests that previous BGD contributes to the overall risk from BGD-induced mortality.

Hatcheries that produced $> 50\,000$ pounds of salmonid fish per year and/or $> 250\,000$ fish per year in 1992 and 1993 were at increased risk from BGD for outbreaks occurring outside of the hatch house, and for all cases of BGD combined. Hatcheries with greater production could be raising fish at higher densities and/or could be employing proportionately fewer staff than the hatcheries with lower production.

The odds of a BGD outbreak was significantly greater for commercial trout hatcheries than for government hatcheries. In addition, the point estimates were large. This increased risk associated with a commercial facility could be a function of employment practices and of the use of fish health specialists to routinely monitor fish health. Because of the practice of promoting experienced employees and because of lower employee turnover, government hatcheries might be more likely to employ experienced fish culturists. Thorburn (1987) found that, in Sweden, vibriosis mortality rates were lower in pen-reared rainbow trout raised on farms run by more experienced trout farmers. In addition, our study found that government hatcheries were more likely to use a laboratory or fish health specialist for the diagnosis of BGD, implying that government hatcheries might have greater access to (or more readily use) diagnostic services than private hatcheries.

The presence of fish in the hatch house water supply was a risk factor for BGD, presumably because the etiologic agent is transmitted from fish in the water supply to the hatchery fish. This finding coincides with the conclusions by Jarp et al. (1993) that migration of anadromous fish into the freshwater supply of the hatchery was a risk factor for infection with *Aeromonas salmonicida* in freshwater salmon hatcheries in Norway.

However, fish in the pond/raceway water supply was not a risk factor for outbreaks in the ponds/raceways. Snieszko (1981) suggested that large fingerlings are more resistant to BGD. The fish were an average of 10.3 weeks old at the time of the hatch house outbreaks and an average of 16.4 weeks old at the time of the pond/raceway outbreaks.

Unexpectedly, we found that there was an association between increased risk of BGD in the hatch house and the use of UV light to disinfect hatch house water. This finding was quited unexpected because of the purported benefits of UV disinfection of water. Proper operation and maintenance are essential for effective function of UV treatment systems. Water flow rate, lamp density and light intensity are among the critical parameters that need to be properly set and maintained to achieve the desired effectiveness. A decrease in incidence would not have been detected by the analysis because one outbreak of BGD during the study interval was sufficient for a hatchery to be assigned

to the case group. More work needs to be done to determine the UV inactivation requirements for individual fish pathogons (D. Conwell, personal communication; Stover et al., 1986).

As the density of susceptible individuals increases, so does the probability that an infectious disease epidemic will occur (Anderson and May, 1992). Not surprisingly, increased fish density was a risk factor for bacterial gill disease outbreaks in the univariable analyses.

Although we have identified risk factors associated with BGD outbreaks, more work needs to be done before comprehensive recommendations for control of the disease can be made. However, based on the results of our study, we suggest the following. First, the risk of a BGD outbreak can be reduced if fish are removed from the hatch house water supply. In the absence of information on hatchery fish density, it is difficult to know whether the reduction in risk will be large or small, but presumably the hatcheries with greater fish densities will be at greater risk from fish in the hatchery water supply. Second, increasing hatchery production is likely to increase the risk for a BGD outbreak. Third, installation of a UV system to disinfect hatch house water will not necessarily prevent BGD outbreaks. Finally, trout producers who have experienced BGD outbreaks in the past are at a high risk for experiencing BGD outbreaks in the future.

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